UNITED STATES PATENT APPLICATION

for

LOW VOLTAGE, LOW Z, BAND-GAP REFERENCE

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LOW VOLTAGE, LOW Z, BAND-GAP REFERENCE.

FIELD OF THE INVENTION

The present invention relates to the field of integrated circuit design.

5 BACKGROUND OF THE INVENTION

In the arena of complex integrated circuits, there are sometimes portions of circuits that require voltage references for proper functioning. A voltage reference provides a precise output voltage, one that is much more accurate than can be produced by a
10 voltage regulator. Its output voltage is compared to other voltages in a system and, usually, adjustments are made to those other voltages based on the reference difference. References are similar to regulators in how they function, but they are used much differently. While regulators are used to deliver power to a load,
15 references are normally used with a small, stable load (if any) to preserve their precision. Only a few of the existing reference designs have the capability to deliver a load greater than a few milliamps while maintaining a precision output voltage. A reference is not used to supply power but to provide a system with an accurate

analog voltage for comparison purposes. The band-gap reference circuit has long been used in integrated circuits for that purpose.

A band-gap reference takes advantage of the electro-chemical properties of a material. In a semiconductor, the amount of energy

5   which allows the material to become conductive, i.e. move current in the presence of a voltage, is known as the band gap energy. The band gap energy is different for a variety of materials. However, silicon, the foundation material for a preponderance of integrated circuits, has a predictable band-gap energy that changes little with

10 temperature over most of the temperature range of normal integrated circuit operations.

The band-gap reference is widely used in almost every application of IC technology. One common method of band-gap implementation is use of current generated by the delta V_{be} of a

15 pair of unijunction transistors which essentially function as diodes. The current then flows through a diode chain to achieve a constant reference band-gap voltage. A significant problem with such simple reference circuits is a high output impedance which can change the reference behavior if the band-gap reference circuit were connected

20 to a high noise stage.

Some early band-gap reference circuits used conventional junction-isolated bipolar-IC technology to make relatively stable low-voltage references. This type of reference became popular as a stable voltage reference for low-voltage circuits, such as in 5-volt

5   data acquisition systems where zener diodes were not suitable.

A common failing in band-gap reference circuits, as mentioned above, is a characteristically high impedance that results in a noisy circuit. Because the demands on a reference get ever tighter with higher precision circuits, a stable low-noise performance is crucial.

10   Another common failing of band-gap circuits is the requirement for a relatively high VCC, substantially higher than the reference voltage. Since a band-gap voltage is almost always very close to 1.2 volts, a minimum value for VCC is usually somewhere around 2 volts. Since modern digital ICs using 1 volt technology are

15   becoming daily more common, the requirement for a higher VCC can be a design limitation.

What is needed, then, is a band-gap reference circuit that has an innate low impedance to allow for stable low-noise operation. A further need exists for a band-gap reference circuit that can produce

20   a usable reference voltage while being powered by a low supply voltage.

SUMMARY OF THE INVENTION

Presented herein is a band-gap reference circuit that has an innate low impedance to allow for stable low-noise operation. This novel band-gap reference circuit can produce a usable, low noise,

5   reference voltage while being powered by a low supply voltage.

The present invention relates to a low impedance band-gap voltage reference circuit which comprises a band-gap reference circuit, a buffer circuit to reduce the impedance and related noise associated with band-gap references electronically coupled with the

10   band-gap voltage reference circuit and a voltage pull-up device electronically coupled with both the band-gap reference circuit and the buffer circuit. The voltage pull-up device acts to reduce the supply voltage required to maintain a stable, low Z band-gap reference voltage.

15   These and other objects and advantages of the present invention will become obvious to those of ordinary skill in the art after having read the following detailed description of the preferred embodiments which are illustrated in the various drawing figures.

BRIEF DESCRIPTION OF THE DRAWING

The operation and components of this invention can be best visualized by reference to the drawing.

Figure 1 illustrates an implementation of a band-gap reference circuit.

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Figure 2 illustrates an implementation of a band-gap reference circuit with an impedance reducing buffer consistent with the conventional art and with embodiments of the present invention.

Figure 3 illustrates a low-Z, low voltage, band-gap reference circuit in accordance with one embodiment of the present invention.

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DETAILED DESCRIPTION

Reference will now be made in detail to the preferred

embodiments of the invention, examples of which are illustrated in

the accompanying drawings. While the invention will be described in

5   conjunction with the preferred embodiments, it will be understood

that they are not intended to limit the invention to these

embodiments. On the contrary, the invention is intended to cover

alternatives, modifications and equivalents, which may be included

within the spirit and scope of the invention as defined by the

10   appended claims. Furthermore, in the following detailed description

of the present invention, numerous specific details are set forth in

order to provide a thorough understanding of the present invention.

However, it will be obvious to one of ordinary skill in the art that

the present invention may be practiced without these specific

15   details. In other instances, well-known methods, procedures,

components, and circuits have not been described in detail so as not

to unnecessarily obscure aspects of the present invention.

The embodiments of the present invention discussed herein

relate to the electronic characteristics of the semiconductor

20   material from which integrated circuit devices are formed. Modern

integrated circuit devices are typically very small and work in very low voltages. Most modern integrated require a stable voltage reference. In some cases, modern digital devices can draw a logic distinction between voltages differing by fractions of volts. Some

5   analog or hybrid devices, such as ADCs (analog to digital converters) or DAC s (digital to analog converters), however, can be required to make much smaller determinations.

Another type of hybrid IC is family of chips employing digital signal processing (DSP). The explosion in telecommunications

10 technology has driven a tremendous amount of progress in DSP chips and the speed demands have driven voltages downward just as in other types of processing. As the voltages have gotten smaller, the impact of noise in ICs, particularly in an environment where an acoustic signal the focus, has steadily gotten more important. One

15 source of noise exacerbation is the innate high impedance of common voltage references.

One method of reducing noise in a reference circuit is by adding a buffer to the output of a band-gap reference. However, the addition of a buffer increases the power demand and can drive up the

20 supply voltage required in order to maintain the band-gap voltage.

Figure 1 illustrates a basic band-gap reference circuit and Figure 2 illustrates a reference with a buffer for noise suppression.

Figure 1 is an illustration of a common Implementation of a band-gap reference circuit. The band-gap voltage at 100 is the sum of the current through transistor 107, multiplied by the resistance of resistor 105, and the base-emitter voltage (VBE) of transistor 103. The current through transistor 107 is controlled by both its gate voltage, which is a function of the action of transistors 106 and 108, and the current diverted through resistor 104, which is controlled by the action of transistors 101 and 102. Transistors 106, 107 and 108 are connected in common at their gates with drains to supply voltage, VCC. The gate to drain shunt of transistor 106 acts to regulate the gate voltages and the current of transistors 108 and 107.

Transistors 101 and 102 are both implemented as bipolar devices in this illustration. With its common base and collector, transistor 102 effectively acts as a base-emitter diode. Transistor 103 is also connected in a common base-collector form and also acts as a base-emitter diode.

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It is the difference in currents between transistors 106 and 107 that produces the stable band-gap voltage. Assume that the current. If I_{106} is the current through transistor 106, that same current is through transistor 101 and resistor 104. In that case by

5   Ohm's law, I_{106} times R_{104} equals the base-emitter voltage of transistor 102 minus the base-emitter voltage of transistor 101, i.e.:

$$I_{106} \cdot R_{104} = VBE_{102} - VBE_{101}$$

then

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$$I_{106} \cdot R_{104} = (VT \ln m)$$

$$I_{106} = (VT \ln m) / R_{104}$$

where: m is the relationship between transistor 101 and transistor 102 and m is larger than unity which means that transistor 101 is "bigger" than transistor 102. This in turn means that, for the same

15   base-emitter voltage and the same emitter-collector voltage, transistor 101 will pass m times as much current as transistor 102.

The similar relationship between transistor 106 and transistor 107 is n. Transistors 106 and 107 are implemented as field effect transistors (FET) in this illustration. Transistor 107

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will pass n times as much current as transistor 106 at the same gate-source voltage which is the constant state in the circuit illustrated because transistors 106 and 107 have common sources and common gates. If i_2 is the current through transistor 107 and i_1

5   is the current through transistor 106 and therefore transistor 101, n = i_2 / i_1 and n is greater than or equal to 1. The current through transistors 108 and 102 is i_3.

The band-gap voltage at 100, then, is:

$$V_{BG} = I_2 \cdot R_{105} + V_{BE_{103}}$$

10   Note that, since transistor 103 is connected with a common base-emitter, it functions as a diode with an innate resistance. Then:

$$V_{BG} = n i_1 R_{105} + V_{BE_{103}}$$

$$V_{BG} = [n (V_T \ln m) / R_{104}] \cdot R_{105} + V_{BE_{103}}$$

15    $$V_{BG} = [n (V_T \ln m) / R_{104}] \cdot R_{105} + V_T \ln (n i_1 / i_S)$$

It must be noted here that the gate-drain shunt of transistor 106 causes the gate voltage of transistors 106, 107 and 108 to seek an equilibrium. The difficulty that arises in such a simple circuit is its inherent high impedance and attendant susceptibility to noise.

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Sub C₂ 7

To overcome this, a buffer can be added to the band-gap circuit as is shown in Figure 2. In essence the same circuit as in Figure 1, the circuitry associated with transistors 201 through 207 and resistors 211 and 212 provides the same functionality as the

5   circuitry in Figure 1. The current source shown at 214 is implemented in this illustration as a MOSFET current source. PNP transistors 203 and 204 share a common base which is shunted to the collector of transistor 203. NPN transistors 201 and 202 also share a common base that connects to V_{BG}, the band-gap voltage.

10 Transistor 205 has a base connected to the common collectors of transistors 202 and 204. The collector of transistor 205 is connected to the drain of transistor 206 which shares a common gate with transistor 207. The common gate of transistors 206 and 207 is shunted to the drain-collector connection between

15 transistors 205 and 206. In the implementation illustrated in Figure 2, m symbolizes the relationship in current flow between transistor 201 and transistor 202. Because their bases are common, the ratio of current flows is constant. The base-emitter voltage of 201 and 202 differs by the voltage across resistor 211.

20   The circuit in Figure 2 differs primarily from that in Figure 1 in the employment of transistor 209. Transistor 209 is

implemented as an NPN bipolar device, which typically have significantly lower impedances than FETs. Transistor 209 connected at its base to common emitters of transistors 203, 204 and 205 and with its collector connected to VCC. This causes transistor 209 to

5 behave as an emitter follower and functions as a buffer. It is well known in the art that an emitter follower can accept a signal at a high resistance level without significant attenuation a reproduce it at a low resistance level and with no phase shift. Therefore, in this implementation, it functions well as a buffer. However, a problem

10 that arises in the use of a buffer is the requirement for a higher supply voltage, VCC, in order to preserve a constant band-gap voltage.

In the band-gap reference circuit illustrated in Figure 2, the required Vcc can be defined as:

15 $$VCC = V_{BG} + V_{BE_{209}} + V_{SOURCE_{214}}$$

where:

$$V_{BG} = 1.25\ V$$

$$V\ _{BE_{209}} = 700mV$$

$$V_{SOURCE\ _{214}} = 300mV$$

20 thus:

$$VCC \geq 2.25\ V$$

Sub C3

The embodiment of the present invention discussed here enables a low supply voltage VCC, as is shown in Figure 3, by the addition of device 320. Device 320 is accompanied by the addition of transistor 308, transistor 310 and current source 313. Current

5 source 313 can be, in many implementations of this embodiment of the present invention, functionally implemented by a MOSFET current source with its source connected to VCC. NPN transistor 309 is connected as an emitter follower for the emitters of transistors 203, 204 and 205. The emitter of transistor 309 is connected via

10 device 320 to the base of PNP transistor 310. It is transistor 310 that provides the final buffering in this implementation. The collector-emitter voltage, V_{CE}, of transistor 310 is the band-gap voltage in this embodiment. In this configuration, Vcc can be very low for a buffered band-gap circuit. The minimum VCC here is:

15 $V_{CC} = V_{BG} - V_{BE310} + V_{320} + V_{BE309} + V_{SOURCE\,314}$

since:

$V_{BG} = 1.25\ V$

$V_{BE310} = V_{BE309}$

then:

20 $V_{CC} = V_{BG} + V_{320} + V_{SOURCE\,314} \cong 1.8\ V$

Sub C4

Note that, in this embodiment, device 320 is necessary to pull the voltage back up and prevent saturation of transistors 201 and

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202. Device 320 can be implemented, in various embodiments, as a resistor or as a transistor with less than 1 VBE. It is important to note that transistors 203, 204, and 205 can be implemented as either bipolar transistors or MOS transistors.

5   Device 320, in this embodiment, can be implemented in a number of ways. It is likely that device 320 will be found to be functional when implemented as a resistor or as a fixed gain transistor. Without regard to the actual implementation, the function of device 320 remains to be the reduction in necessary

10   supply voltage in order to produce a functional buffer across the operating range of the band-gap reference circuit. The combination of device 320 and transistor 309 acts to pull the VBE of transistor 310 towards VCC which means that the buffering that is done by transistor 310 can be accomplished at a lower VCC. In this fashion,

15   the buffering necessary to achieve a low impedance is enabled yet the normally high Vcc attendant to the implementation of buffering is obviated. A low voltage, low Z, band-gap reference circuit is thus embodied.

A novel band-gap reference circuit has been disclosed. The

20   foregoing descriptions of specific embodiments of the present invention have been presented for purposes of illustration and

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description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to

5 best explain the principles of the invention and its practical application, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the Claims

10 appended hereto and their equivalents.